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GLACIOLOGICAL RESEARCH SUB-COMMITTEE

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(Second Edition)

MEASUREMENTS REQUIRED ON A GLACIER IN AN AREA WHICH IS UNKNOWN AND UNMAPPED.

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I. INTRODUCTION

This note is prepared as a part of the policy of the Sub-Committee to encourage, co-ordinate and improve the standards of glacier research. It is intended to help small expeditions visiting areas where little is known about the conditions of the glaciers.

It is hoped expeditions will realise that, in accepting and making use of the advice given in the note, they are under an obligation to assist the Sub-Committee in pursuing its policy by preparing and submitting a duplicated report on their findings, even though they may not be of outstanding importance and warrant publication. An expedition's work is incomplete unless at least its findings are assembled in readable form and the existence of those findings is published.

Even when the material is unsuitable for a scientific paper for submission to a learned journal, it may be of great value to anyone subsequently visiting the area. For example, a 48 year old typed report by Ross G. Marvin of the position of the edge of the Ellesmere Island ice-shelf, which was deposited in the U.S. National Archives,

became of immense value when the edge was resurveyed in 1954 the extent of the retreat of the ice became known.

II. REASONS FOR GLACIOLOGICAL RESEARCH

Glaciers are studied for a variety of reasons, including the following:

1. In the polar regions, which are being exploited rapidly, ice is the dominant ground material and it plays the same role as the soil and the rocks do in temperate and tropical areas.
2. In mountainous areas glaciers provide valuable water sources in dry summers for hydro-electric power and water supply, yet their movements can lead to disasters when an ice-dammed lake is suddenly released.
3. Glaciers are good indicators of past and present climatic changes.
4. A glacier is a good example of a deformable crystalline material on a large scale at or near its melting point.
5. An understanding of glacial erosion and deposition is of value both in areas which are glaciated at present and in those from which glaciers have receded. For example, interpretation of the ground conditions for agricultural and constructional purposes over most of the British Isles is not possible without this understanding.

III. PURPOSE OF THIS NOTICE

This note explains what is needed (a) to put on record the present dimensions and the regime of a glacier, and (b) to obtain some information on this glacier that prepares the ground for fundamental glaciological research. No attempt is made to indicate the lines along which detailed investigations whould be directed in order to seek out physical laws of general validity. The note is written in terms of a glacier having a period of surface melting. The measurements required are given in order of priority and also generally in order of ease of obtaining the measurement.

It is assumed that only about 5 people will be engaged in the work for a period of about 3 months, that the area is difficult of access and is unlikely to be visited frequently, and that supplies and equipment will be back-packed or sledged into the area. When more people are available and more supplies can be transported readily, for example by using aircraft, the measurements should be made in greater detail.

IV. GENERAL ADVICE

a. Selection of Area.

Expeditions are often attracted by the adventure of visiting a completely unknown area, but the chance of completing a useful amount of glacier research is likely to be less than in an area which has already been reconnoitred. A previous aerial survey is of considerable help in selecting an area, in finding ways of access to the glaciers, and in gaining some knowledge of their character. Advice should be sought from the geographical society and the mapping authorities in the country to be visited.

Pioneering expeditions should not be disappointed if they fail to complete many of the suggestions made in this note, but they should remember that others will return to the area and that the value of their own work will be considerably enhanced if the original measurements can be repeated in precisely the same places.

There is a great merit in the continuity of records and in the comprehensive study of one aspect; miscellaneous records are of less value. Organisations sponsoring expeditions should note the economy and merit of sending a sequence of parties to the same area so as to obtain a comprehensive fund of knowledge. It is very useful to revisit a glacier which has already received a reasonable study, after a lapse of 10-20 years.

b. Selection of Glacier.

A simple valley, corrie, or piedmont glacier, without low level tributaries, or a clearly-defined lobe of an ice cap should be chosen. Its surface topography should be fairly uniform; it should be completely accessible at any time and be easily traversed in one day. Where no previous studies have been made on any glacier in the area, the chosen glacier should be typical of the area. Observations of the terminal moraines and of the vegetation around the glaciers, and studies of aerial photographs, if they exist, will help in this choice of a typical glacier. It may appear that some glaciers are advancing or stationary while others are in retreat, and hence no one glacier is typical. If so an attempt should be made to find the reasons by finding which glaciers have high and low, and/or small and large accumulation areas, and which glaciers come from the windward and leeward sides of the mountains.

c. Travel Precautions.

Though most of the work can be done by two people working together it is advisable, certainly during some seasons and in some parts of every glacier, to observe the usual mountaineering precautions and to travel with three persons roped together. Adequate precautions should also be taken in crossing partly thawed lakes and river courses, as well as in fording streams both on the glacier and below it. In summer the levels of lakes and rivers fluctuate considerably from week to week and even during one day. Rope bridges and anchored rafts may be necessary at the height of the melting period to cross a channel which is ankle deep in the autumn.

d. Surveying, Experience and Methods.

Experience in various methods of surveying and in the use of surveying instruments is essential. Surveys should be made in one of the following ways:

1. Tape and pacing, compass, altimeter.
2. Taped base line, plane table, alidade, altimeter.
3. Taped or subtense base line, theodolite, ground photogrammetry.

Preference should be given to the preparation of a general map of the whole glacier boundary containing accurate fixed

points rather than a partial coverage in greater detail. Triangulations or closed traverses are better than open traverses. Tacheometry is only convenient where great detail is sought. The survey should be referred to three or more permanent reference marks whose positions should be published, stone cairns securely built in safe places and brass plugs set in place with a small hand rock drill are recommended. Survey calculations should be taken in the field to a stage that ensures there are no serious observational errors; cross-checking observations should be made always.

Air and ground photogrammetry may be used conveniently, particularly for providing more detailed surveys of complicated areas of glaciers and icefalls. Some triangulated points are required in every photograph and it is wise to process some film in the field to ensure satisfactory results. Photogrammetric plotting machines are only available in a few places.

In any case good photographs of the glacier should be taken, the time, date and position of the camera being recorded in such a way that the camera position can be repeated exactly by subsequent visitors.

V. GLOSSARY OF TERMS

Accumulation and ablation. All water, in solid or liquid form, added to a glacier is called accumulation; it is eventually lost from the glacier in solid, liquid or vapour form and is then called ablation. The duration of the storage of any particular item of accumulation can vary enormously, from less than a day to many hundreds of years. In the course of its stored life the accumulation may change its form and/or travel from one part of the glacier to another by water seepage, wind drift of snow, and ice flow. The terms accumulation and ablation therefore have an explicit meaning only when applied to a particular part or the whole of a glacier, and when the interval of time is specified. Both items are measured as quantities of water; in cm^3 or m^3 when applied to the whole glacier and in cm. of water at a particular place on the glacier.

The following specific definitions are applicable to the whole glacier for the interval of one budget year.

Gross annual accumulation. The total volume of water added to a glacier by all forms of precipitation and drifting snow during a budget year. In the ablation area the gross annual accumulation is temporary and is all lost by the end of the budget year.

Net annual accumulation. The annual nourishment of a glacier. The net amount of water added to a glacier at the end of a budget year. The accumulation area is that part of the glacier surface where the net annual accumulation remains deposited at the end of the budget year.

Gross annual ablation. The total amount (in cm^3 or m^3 of water) of snow or ice in a glacier which is consumed by the processes of melting, evaporation, wind erosion and calving acting on a glacier in a budget year. Except in the Antarctic, the greater part of the gross annual ablation of a glacier usually takes place by melting at its upper surface during the summer season. This period is called

the ablation season; there may be more than one such season, and some ablation may occur throughout the budget year.

Net annual ablation. The volume of water actually lost from the glacier by drainage, evaporation, wind erosion and calving in a budget year. The difference between gross and net ablation is due to such items as melting of temporary accumulation especially in the ablation area, the refreezing of water on the glacier surface or within its mass, the internal storage of water and the transport of snow from one place to another. The net ablation area is that part of the glacier surface, usually at the lower altitudes, where some of the material accumulated in previous budget years becomes net ablation in the current budget year. The area is usually characterised in summer by bare ice and often by rock debris at its surface.

Budget year and regime of a glacier. Every glacier undergoes, on account of the climate, a succession of changes, which are repeated approximately from year to year. The volume of a glacier is therefore continuously changing and measurements of net changes over the years can only be made with respect to a particular annually-repeated state. On a glacier with a definite period of melting the surface area, where net ablation occurs, becomes a maximum at a certain time. This time is conveniently referred to as the beginning and end of the budget year; the period is not necessarily a calendar year. Other definitions for the budget year may be necessary or more convenient in other climatic conditions. The boundary on the glacier surface of the upper limit of the net ablation area at the end of the budget year is called the equilibrium line, above it lies the accumulation area.

The regime of a glacier is positive when there is a net addition to its water volume in a budget year, and negative when there is a loss. The amount is equal to the difference between the net annual accumulation and the net annual ablation.

Firn. Granular and compact snow characteristic of the accumulation area at the end of a budget year. The firn line is the highest level on a glacier to which the winter snow recedes during a period of ablation; it can be seen readily, the white appearance of the firn contrasting with the bluish-grey appearance of the bare ice. At one time it was thought that the firn line separated the areas of net accumulation and ablation, but now it is realised that dense ice accumulation usually occurs between the firn line and the equilibrium line.

Medial moraines. Trails of rock debris on the surface of a glacier in the ablation area originating from the confluence of lateral moraines at higher glacier junctions, or from nunataks (rock islands entirely surrounded by ice). Many moraines which superficially appear to be heaps of rocks, are ice-cored.

Lateral moraines. Trails and ridges of rock debris at the sides of glaciers composed of rocks fallen from the valley sides; these moraines may become separated from a glacier in retreat.

Terminal or end moraines. On an ice cap lateral and terminal moraines become synonymous and are called edge moraines. The source of debris is then sub-glacial unless they are fed by medial moraines from nunataks. Terminal

moraines are ridge-like tips of rock debris deposited by ablation at the snout of a glacier and left in distinct concentrations when the glacier recedes from a relatively steady position. The rock debris may derive from both medial and lateral moraines and from sub-glacial sources. Terminal moraines may also be formed from valley debris pushed up in front of an advancing glacier.

Eskers. Sediments laid by glacial rivers flowing wholly or partly within ice boundaries. Old eskers usually appear like steep ridges of sand and may show the meanders of the original river, but, owing to the disappearance of its ice boundaries, the bedding of the sediments become disrupted by slips along the edges of the esker. Glacial lake deposits of similar origin are often called kames.

VI. MEASUREMENTS REQUIRED

a. Surveys.

1. A plan of the glacier terminus, or ice cap edge, with photographs taken from surveyed points in known or calculable directions.
2. A plan of the limits of the glacier; the slopes of the valley walls are of interest if the depth of the glacier has been determined.
3. The boundary of the firn or equilibrium line.
4. A plan of the positions of prominent terminal moraines and of the terminal lake. Soundings of the latter; its surface level. Determine whether the moraines are ice-cored.
5. Positions and numbers of lateral moraines.
6. Record the types of vegetation and their proximity to the glacier boundaries and the moraines.
7. If debris is present on the glacier snout, record its nature, e.g. large boulders, rock flour, eskers, etc. and map its extent.
8. A longitudinal profile of the glacier surface, generally in the centre of a valley glacier and as far as can be judged along the line of maximum surface velocity (the distortion of any transverse bands and the symmetry of crevasse patterns will assist in determining the points of maximum velocity). Typical surface profiles chosen to follow lines of maximum slope should be measured across an ice cap.
9. Record the location and orientation of any crevasse fields relative to the longitudinal profile.
10. Generally record the presence or absence of noticeable transverse dirt bands (their number and spacing, if regular), ice falls, longitudinal and traverse ice bands of unusual structure, especially bands of fine crystals (of a width comparable to crystal size), Forbes bands (their number and longitudinal spacing), and any waves below ice falls, bends or constrictions in the valley.
11. Record the position of any medial moraines and locate their source. In particular, record the upper and lower ends of any medial moraines of limited length. Survey the positions of a very few large boulders and daub all surfaces thoroughly with a bright-coloured durable paint (red lead in gold size, or red or yellow

alkyd resin paint) for subsequent identification.

12. Measure the height of the ice cliff bounding a lake or the sea; measure the horizontal surface area of the snout lost by calving during a season; make soundings in front of the ice cliff.

b. Accumulation and Ablation.

The progress of accumulation and ablation should be followed at four elevations, at least one near the snout, one centrally placed in the accumulation area, and two at an intermediate position, preferably just above and just below the equilibrium line. The sites should be chosen so that the measurements are representative of the mean values at those elevations, and a few preliminary soundings and excavations may help in the selection of the sites. Where there are sufficient personnel the measurements should be made much more extensively so as to obtain some estimate of the glacier's regime.

Measurements should commence at the glacier snout before the ablation season commences and they may be made more easily in the ablation area than in the accumulation area, since last year's ice surface provides a readily distinguishable reference horizon.

1. Accumulation Measurements.

In the ablation area simple soundings should be made with a long metal rod or tube to locate the previous summer's ice surface and to measure the thickness of the overlying snow. It is advisable to dig a pit occasionally or to make a boring to find out what is being sounded and what lies below. In areas where the snow thickness is fairly uniform and the ice surface is not irregular, depth-density measurements should be made to ascertain the total water equivalent of the snow cover in centimetres of water.

In the accumulation area it is more difficult to establish the surface corresponding to the end of the previous summer season or budget year, particularly where there has been no melting. Sometimes it is necessary to follow through in detail the changes in the character of the near-surface snow for a summer season before reaching a conclusion as to which buried feature represents the snow surface horizon at the end of the previous summer season. Dirt layers are not always a reliable guide. Where there has been some summer melting, an open-textured layer of large depth-hoar crystals will usually be found overlying the last thin crust of the previous summer and a typical bed of hard summer firn. In this case the surface of the hard firn may be sounded over large areas and the depth-density profiles and the water equivalents measured at representative points as in the ablation area.

The above measurements in the ablation and accumulation areas will give the gross accumulation to date, and it will be less than the gross annual accumulation by the amount of precipitation to be deposited before the end of the budget year. During the ablation season the latter can be measured approximately by visits to the areas after every snowstorm and by measurements of the density and thickness of the newly-deposited snow. It will be necessary to measure as ablation any fresh snow eroded and blown off the glacier if it has

already been included as accumulation. If there is rain it must be measured and a simple gauge can be improvised. These measurements need to be continued until it is evident that the ablation season is over.

All the above measurements, if carried out in sufficient detail will enable a map to be prepared of the gross annual accumulation in cm. of water and they may be integrated over the glacier area to give the gross annual accumulation of the glacier in cubic metres of water. Evaporation during the winter has been excluded in this measurement as it requires winter occupation, but it is not required for assessment of the regime.

To estimate the net annual accumulation it is necessary to follow the progress of ablation at the various elevations during the summer and to find out how much of the gross accumulation remains with the glacier at the end of the budget year (i.e. the net accumulation) and how much of it is lost. In some climates it may be possible to measure the net annual accumulation directly at the end of the budget year by means of a series of depth-density profiles in the accumulation area, but only where melt-water does not descend into the accumulation of previous years; it is not wise to rely on this method in an unknown area.

2. Net Ablation Measurements.

Little net ablation of the snow will occur in the summer until it reaches the melting point throughout its depth and for this reason it is worthwhile to follow the temperature profile in the snow at an early stage.

Reference levels for ablation should be established by setting vertical stakes as deeply as possible before melting commences, so that there is no risk of them sinking or melting out later in the season. They should be sunk in the ablation area at least to the level of the dense glacier ice and preferably drilled into it several feet (1 - 2 m.). It is convenient to place the stakes near to the accumulation measurement sites but not so close that old pits and other disturbances influence the rate of melting. Stakes are least disturbed upstream of pits. On insertion, the total length of the stake, the amount exposed above the snow surface and the depth of the snow cover should be measured. The nearby measurements of the depth-density profiles made in connection with estimating the accumulation may be used for following the ablation.

The rate of ablation and the gross ablation of the snow cover need not be measured, unless heat balance or microclimatic measurements are being made, but as soon as only 3 ft. (1 m.) of snow is left overlying the ice the stakes must be drilled into the ice as far as possible. A stake initially placed on the surface of the ice will usually be found to be frozen in and it will be necessary to dig it out. In doing this it will be found that the ice level has risen around the stake by a few inches. The increase should be measured as it is refrozen melt-water superimposed on the previous summer's ice surface and it is not until this superimposed ice has melted away that the net ablation commences at the surface of the glacier. Disturbances caused by stake extraction at this stage may call for the fresh stake to be set in a new position nearby. If a local and abnormal concentration of surface debris is revealed when

the original ice surface becomes exposed, the stake should be moved to a more typical site.

The total thickness of ice lost relative to the previous summer's surface (i.e. the net ablation) should be measured and it is best to make a few measurements of the ice density to convert the measurement into its water equivalent. Where net ablation measurements are carried out in sufficient detail a distribution map may be prepared and the total net annual ablation of the glacier surface calculated.

Measurement of gross ablation throughout the accumulation area is not essential to a regime study, as the net ablation is usually small and includes only evaporation and wind erosion. It is more difficult to measure than is sometimes suggested. A common method of measuring the melting assumes that any increase in the density of a layer or layers of snow (i.e. decrease in thickness) is entirely due to melting, but this is not generally true. The snow can compact under its own weight and by recrystallization when the temperature is below the melting point. Moreover, when the snow surface is melting the melt water can descend intermittently and irregularly into the lower snow and it is difficult to discover its depth of descent. Temperature profiles may be of some help in establishing the depth to which the melt water descends, but they are not much help when the melting is intermittent and small, because then the descent of water is irregular even over a small area.

At some elevations, and especially just above the equilibrium line, on all glaciers the melt water descends into the firn of previous years and it may be difficult to establish a reference level which is sufficiently deep. In the firn just above the equilibrium line some of the descending melt water may give rise to net ablation late in the summer. The water permeates laterally through the firn and discharges over the dense ice surface of the ablation zone. It is responsible for the very slushy terrain and the streams which are common just below the current firn line. As yet no method of measuring the net ablation in this type of area appears to have been found and it is usually omitted from the glacier regime.

The equilibrium line on the glacier, where there is no net addition or loss of ice or snow to the surface of the glacier, should be mapped at the end of the budget year. This is not a well defined line, but a slushy region, particularly where the surface slope is small, which is difficult to travel over on account of the outflow of melt water mentioned above.

3. Regime.

The glacier regime may be assessed in two ways. It is equal to the gross annual accumulation laid on the entire glacier surface in a budget year less the net ablation for the same period. The latter item should include calving from the snout, evaporation and any melting at the sole of the glacier. Sub-glacial rivers discharge from the snouts of most temperate glaciers throughout the winter and it may be possible to gauge the flow by means of a weir. This loss is not often measured as it is not likely to vary much from year to year.

The regime is also equal to the net annual accumulation added in the accumulation area at the end of

the budget year less the net ablation of dense ice in the ablation area from the level of the surface exposed at the end of the previous budget year. The method used to assess the regime will depend on the climate, the duration of the observations and the measurements made. The comments made on the previous method apply in this case also.

4. Equipment Needed.

The equipment required for the above accumulation-ablation measurements is:

(i) Timber stakes of ramin wood (10 ft. long), red bunting markers.

(ii) Light portable ice drill (at least 10 ft. and 1 to 1.5 ins. diam.).

(iii) Aluminium alloy sounding tube, about 1 in. diam. x 10 ft. long.

(iv) Flexible steel rule (6 ft.).

(v) Aluminium alloy snow shovel.

(vi) Ice axe.

(vii) Snow sampling tubes.

(viii) Roman or spring balance to weigh snow samples.

The recommended type of stake and the method of planting it will be mentioned later, together with some advice on ice drills.

5. Snow Cover Density Measurements.

There are several suitable methods of measuring the snow density. They all consist of sampling the snow in a tube of known volume and weighing its contents.

a. The traditional method is to dig a pit and sample each and every snow layer at frequent intervals by means of a thin-walled tube about 3 ins. diam. and 4 ins. long which is pushed into the wall of the pit. Alternatively more or less continuous vertical sampling may be made close to the face of a pit wall with the same tube. Ice layers cannot be sampled and allowances have to be made by thickness measurements.

b. Coring from the surface may be carried out by a 3 ins. diam. thin-walled sampling tube of sufficient length which is pushed or rotated downwards to recover the total snow profile. A plain sharp cutting edge to the tube will penetrate very thin ice crusts without disturbing the snow density appreciably, but where the ice layers are thick the sampling tube should be equipped with peripheral saw teeth and the tube rotated through the ice. A sampler of the so-called Mount Rose type can be used, and the coring auger used by the U.S. Army, which consists of a thin-walled tube fitted with two leading cutters feeding into a spiral elevator, is reported to be satisfactory.

All sampling methods disturb the snow to some extent and change its density, and, particularly where much loose snow has to be sampled, it is wise to check the

sampling method by very carefully cutting to size a rectangular block from the wall of a pit. This method causes least disturbance, but is too slow and tedious to use generally.

c. Glacier Temperature.

Unless deep drilling equipment is taken it will be possible to measure only the glacier temperature down to the level of zero annual change, and quite a light portable drill reaching to 30-40 ft. will usually be sufficient for this purpose. Where melt water rivers discharge beneath the glacier it may reasonably be inferred that the lower part of the glacier is melting, and the existence or absence of these rivers should be noted. Where the rivers discharge from the glacier through tunnels in the ice or through deep gorges entirely within the ice, and which never extend to the rock bed, it is an indication that the ice is below the melting point. Eskers formed on the surface of the glacier snout are also an indication of this temperature condition.

A hole 1 to 1.5 ins. diam. should be bored at three or four elevations adjacent to the accumulation-ablation sites before any melting begins. At intervals of about 5 ft. in depth a lagged thermometer should be lowered to the bottom of the hole, left 15 mins. until it reaches a steady temperature, and removed and read within a minute. This will determine the temperature at each depth to the nearest 1/5 °C. These boreholes might be used subsequently for the insertion of ablation stakes.

A suitable lagged thermometer may be constructed as follows: an ordinary glass stem thermometer is placed centrally in a somewhat longer length of glass or transparent plastic tube about 0.75 in. internal diam. The ends of the tube are sealed with corks or polythene plugs which hold the thermometer axially inside the tube and retain the lagging. The lagging consists either of kerosene, which fills the whole tube, or a plug of paraffin wax surrounding the lower bulb end of the thermometer. The ends of the tube may be protected from damage by short lengths of rubber tube bound on with wire. A small lead sinker can be attached to the lower end for use in water and a metal loop can be fixed to the upper end for attaching a cord.

If seasonal temperature changes are sought, a cable of thermistors should be lowered into the hole after measurements with the lagged thermometer. For these observations to be any value in the ice of the ablation area the hole must be filled with water that is allowed to freeze for at least a week before surface melting begins on the glacier. In a firn area the hole should be packed tight with snow and an attempt made to form plugs of ice by running in a little water at the level of each existing dense ice layer. If this is not done the first flush of surface melt water will descend quickly to the bottom of the hole and upset the temperatures. In an area where there is no melting, the holes have simply to be filled with snow. The electrical cable should be polythene insulated and is best led away horizontally from the hole 3 ft. or so below the snow surface. This will avoid melting from radiation absorbed by surface cables or heavy accumulation of rime falling from suspended cables and upsetting the conditions. Readings should never be taken during the operation of adjacent radio transmitters, otherwise stray potentials may be recorded.

Where extra weight is not a problem thermocouples should be used in preference to thermistors.

d. Surface Velocities.

There are numerous records of surface velocities of glaciers along transverse lines in the ablation area, but there is a scarcity of measurements, (1) close to rock boundaries, (2) at terminal ice cliffs, (3) on ice falls, (4) along longitudinal lines, and (5) generally in the accumulation area. All measurements may be made by traditional surveying methods, but for (3) time-lapse photogrammetry is very suitable, and it may also be convenient for (2).

In the ablation area small painted stones two inches across, and distinguished by larger painted stones placed on top or close by, may be used to mark points on the glacier where the displacements are large; otherwise timber stakes must be drilled into the ice. In the accumulation area it is much more difficult to fix markers which will survive for any length of time, on account of the snow melting in summer and the piling-up of snow in the winter. Weak stakes are readily bent over or broken and buried by local creep of the surface snow. No completely reliable stake seems to have been found, but experiments should be made with white-painted aluminium alloy tube with thin walls and 2 to 3 in. diam. in lengths of 15 - 20 ft. It may be an advantage, where the temperature is below $0^{\circ}C$, to plug the lower ends of the tubes and fill them with water so as to reduce the risk of buckling. It is particularly difficult to get stakes to survive during winter on steep snow slopes.

Theodolite surveys of the markers are best made by intersection from three or four fixed stations on the rock boundaries (or stable ice-free moraines). A transverse line of markers may be lined-in by theodolite across the glacier and their horizontal displacements in the general direction of flow measured in about a month's time by realignment and simple offset measurement with a tape. For alignment good signalling equipment, such as large flags, binoculars and powerful blowhorns or whistles are essential, even on a glacier a ¼ mile wide. On irregular wide glaciers portable radio is essential. Triangulation is necessary on wide glaciers and on ice caps; on the larger ice caps and ice shelves the difficulties are greater still and there is a dearth of information; astronomical fixes at long intervals are the only method.

When theodolite stations cannot be placed on the rock boundaries, as for example on an ice cap or where the rocks are unclimbable, the entire triangulation survey may be made from the ice. In any case the glacier surface is often a convenient place to put a base line whether it is measured by subtense or with a tape. Prominent natural rock features may be intersected from the ends of a glacier base line and those same features resected from the glacier movement markers. The resection is repeated, say one month later, and subsequently if possible. At least three and preferably more natural features should be used, and they should be chosen so that good intersection angles are obtained at the glacier markers. Both vertical and horizontal angles should always be recorded. Accurate naked eye and telescopic view sketches must be kept of the natural rock features in case they change in colour and appearance as the seasons change or memory lapses.

Observations are best made in rather overcast weather to avoid refraction problems, which are acute on glaciers in fine sunny weather. Vertical angles should be measured in both directions in similar weather conditions if accurate vertical distances are sought. A heap of ice crystals piled around the theodolite legs will reduce the local movement of the tripod on bare ice and eliminate it if the glacier is below the melting point.

It is not always essential to triangulate every glacier marker; intermediate points in a transverse or longitudinal line may be fixed in relation to two triangulated points by taping the intermediate distances and measuring the local vertical and horizontal angles between the markers. Accurate measures of the local strain rates (rates at which points a known distance apart come together or separate) are often of more value than precise determinations of the absolute velocity.

Measurement of the ice motion close to rock boundaries may be made by simple tape triangulation from two stations on the rock at a known distance apart.

e. Timber Stakes and Ice Drills.

Timber stakes should be used for long and short term movement studies in the ablation area, for short term purposes in the accumulation area, and for all accumulation-ablation measurements made at frequent intervals. They should be square in section, straight-grained and free from knots. Ramin is a good and suitable wood and stakes 1 in. square by 10 ft. long have proved very satisfactory. These stakes are driven into holes, drilled with a 1.25 in. diam. drill, with a wooden maul. In dense ice it is necessary to use a small plane to remove some of the square corners to effect a fit, which is easily done by trial and error when the hole has been drilled.

When the ablation between visits is likely to approach or be greater than the length of the stake (10 ft.), the hole may be drilled 20 or 30 ft. deep and one stake driven down to the bottom of the hole by means of a maul driving an aluminium rod which fits the top of the stake. The boring rods may be adapted for this purpose. Alternatively, several stakes may be driven down one on top of the other. Buried in the ice in this way, the ablation area stakes are quite safe from possible damage by winter storms and the creep of surface snow. Every stake should be clearly and permanently marked for identification.

There are now some reasonably efficient ice drills which can be used for the insertion of stakes. Different drills are needed in temperate ice and in 'cold' ice, and as a matter of fact it is easier to drill in cold dry ice than in ice at its melting point. Since improvements in ice drills are continuously made, reference may be made to the Sub-Committee for details. Two types of wood auger suitably modified work well in temperate ice.

f. Glacier Thickness.

If measurements of glacier thickness are to be made they should be made by geophysical methods; the techniques and the equipment are very specialized and such a study is a

major undertaking. On a smooth ice cap or ice sheet remote from mountain masses, gravity measurements should be made along lines of maximum slope by means of a gravimeter of the 'Worden' type. Measurements must also be made of the gravity on the rock in the area. Ice in mountainous areas should be sounded by seismic methods. On valley glaciers the seismic surveys should be made along transverse lines at regular intervals along the longitudinal profile so as to obtain a series of transverse cross-sections of the ice. Measurements should be made of the wave velocities in the local ice.

Where possible the thickness should be checked by direct measurement. For example, the depth of water can be measured in front of an ice cliff, in temperate ice a small hole may be melted through to the bedrock by an electro-thermal drill, and in low temperature ice a hole may be drilled mechanically. The latter two tasks are major projects. On a smooth ice cap or ice sheet both geophysical methods may be used so as to obtain a check.

VII. FIELD NOTES AND RECORDS

Keep a daily diary of your movements and activities. Record all your observations and ideas in pencil in several pocket books, date every page, do not rely on memory. Tabulate routine measurements. Be tidy. Before you close a piece of work look through all your observations to make sure that all essential data have been obtained. Make a note of what measurements are still needed. Review your programme of work every week.

Fair copy (again in pencil) and calculate into larger notebooks kept in camp; do this whenever the weather is unsuitable for field work and try to allocate some time to this task every day.

VIII. PREPARATION OF REPORT

Be concise as possible. Remember particularly that the reader has no idea of the conditions in the area and that he wants to go to the area in a few years time to repeat your observations and to find out quantitatively what changes have taken place in the glacier.

Give an account of the topography, the glacierization, and the weather and the sequence of changes on the glacier associated with it.

Tabulate and evaluate your data as far as possible. Prepare all maps and diagrams in a form in which they can be reproduced and reduced if necessary, and if you are not a draughtsman get someone to help you. Insert a few photographs to illustrate the glacier generally and its snout in more detail; record in detail with the help of a map the position from which they were taken.

If the original data have been deposited state where.

The Sub-Committee may be able to advise on the calculation and evaluation of the data, and on the preparation of the report.

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Technical Note No.2

Measurements required on a glacier in a known area

I. PURPOSES OF GLACIER RESEARCH.

Measurements on glaciers may be classified as follows:

(a) Measurements of the properties of typical glaciers which give information about the general state and behaviour of glaciers; these measurements allow us to understand what is going on in a glacier, how the ice accumulates, flows and ablates away, how the temperature distribution occurs and how glaciers of different sizes, shapes and geographical locations differ from one another.

(b) Measurements designed to test current glaciological theories or to provide basic data for the formulation of such theories.

(c) Measurements made for engineering purposes, for example, measurements to discover the hydrological balance of a glacier's catchment area in relation to weather conditions and the future behaviour of the glacier's snout for the design and operation of hydro-electric, water supply, flood prevention or irrigation schemes. For these it may be necessary at the design stage to know such things as ice thickness, ice velocities and the extent of subglacial streams, and it will be necessary to establish routine measurements of melt-water discharge, accumulation and ablation, and to take meteorological observations. Such schemes often provide magnificent opportunities for measurements of fundamental glaciological interest, and such observations are to be encouraged. The work at the design stage will often be carried out by consultants and specialist contractors on behalf of a government, public or industrial organization, while the routine measurements will be made by the organization. The Sub-Committee would much appreciate being informed of any such schemes, and of resulting opportunities for special investigations.

(d) Measurements of the budgetary state of glaciers in an area made as a record of changing events on the earth, and for correlation with climatic changes. For this work continuity in programme and personnel is most desirable, and such work is best carried out by a governmental or public body in the country in question.

This note is primarily concerned with measurements of the type outlined in (a) and (b) above, though it will also be of interest to those planning measurements of the type described in (c) and (d). It must be emphasized at the outset that it is most desirable that measurements should be made of as many properties as possible on a small number of glaciers, so that the results of different workers can be compared and correlated. The glaciers chosen should be varied in type and location, but it is recognized that many important properties of glaciers have never been measured because of the expense of the special equipment required, and they will only be possible if carried out in cooperation with engineering enterprises. This may well therefore determine which glaciers are most suitable for other measurements, and so this note is partly directed to those bodies which can afford opportunities for glaciological research.

II. MEASUREMENTS OF STANDARD GLACIOLOGICAL VARIABLES.

In this section we shall consider the measurements which give a general description of a glacier and of its variation with time.

Any expedition visiting a glacier should start by discovering what measurements have been made of such variables in the past, and whether continuing, routine measurements are being taken on the glacier it is proposed to visit, or on other, similar glaciers in the neighbourhood. If measurements are being taken on another similar glacier but not the one it is proposed to visit, it should be considered whether it is not desirable to change over to the glacier being studied in this way.

If some or all of the measurements mentioned in this section are not available, the expedition may have to undertake some of them, if the interpretation of its results depends on them. In such a case the advice given in Technical Note No. 1 entitled "Measurements required on a glacier in an area which is unknown and unmapped" may be of value. Copies of this note are available from the Sub-Committee.

Some quantities which it would be most desirable to consider as standard glaciological variables, such as the distribution of velocity with depth, involve complicated methods and expensive equipment, and so are considered in section IV below.

(a) Survey of the glacier. A map of the ice edge, and particularly of the glacier terminus is needed for most investigations, and measurements of the retreat of a glacier are the most common and in many ways the easiest routine measurements. Longitudinal and transverse profiles of the glacier at standard lines should be taken at frequent intervals, both surveys being related to trigonometric points which are known not to be moving. Many moraines are ice cored, and it is most undesirable to use survey points on moraine unless such points are further related to points on solid rock, or to the national trigonometric survey.

(b) Accumulation and ablation. Routine measurements of accumulation and ablation can be of two types; they may attempt to discover the rates at various points on the glacier throughout the year, or they may aim only to give the nett accumulation or ablation over the whole year. In either case it is desirable to make the measurements at the same point each year, refound trigonometrically from fixed survey marks. Details on the methods advised for making the measurements are given in Technical Note No. 1. If such measurements are not being made as a matter of routine, useful work can be done by an expedition during a summer field season by digging pits at various points in the accumulation area, and measuring the thickness and mean density of the firn layers between successive summer ablation horizons. In this way the amounts of nett accumulation for several past years may be found. In the ablation area measurements of the ablation can be made throughout the melting season by measuring the fall of the ice surface relative to wooden stakes, which might well be the stakes used for measurements of glacier flow. Care should be taken if stakes are to be used for accumulation measurements, however. This has been discussed by Swithinbank.

Reference: SWITHINBANK, C.W.M. The use of stakes in measuring the accumulation of snow on glaciers. Union Géodésique et Géophysique Internationale, Association Internationale d'Hydrologie Scientifique, Assemblée Générale de Rome 1954, Tome 4, (pub. 1956), p. 128-31.

(c) Discharge of melt water. Measurement of the rate of discharge of streams below the snout of a glacier provides a

way of determining the rate of ablation over the whole glacier, and is a useful measurement.

(d) Glacier temperature measurements. It is very desirable to discover whether the glacier is temperate at all points along its length, that is to say whether, below the thin layer affected by the cold wave from the last winter, the glacier is at the pressure melting point. Measurements of temperature should therefore be made at various altitudes to see whether the temperature becomes zero below this winter wave. Measurements early in the ablation season (or even at the end of the accumulation season) are also of value, as they allow some estimate to be formed of the mean winter temperature. A plot of temperature versus depth in the accumulation region of the glacier should be made. Measurements at various longitudinal positions are useful, as they allow a correlation to be made with glacier flow, accumulation, and atmospheric lapse rate measurements.

(e) Velocity measurements. These should be made by surveying the positions of markers on the glacier. Over a short period stakes bored into the glacier are the most suitable form of marker, and if they are used the three-dimensional velocity of the ice can and should be measured. Over a long period, unless the glacier is visited regularly, stakes will either ablate out or be covered up, so in the accumulation area tall metal stakes must be used, so that they can be detected with a mine detector, while in the ablation area coloured stones can be used. This is naturally less accurate than using stakes, but can give useful results. In several cases of routine investigations rows of coloured stones, a different colour for each year, are laid across a given transverse line, and such stones of the previous year as can be found are surveyed each year.

In the case of a valley glacier, lines transverse to the glacier should be used, with one marker as near to the edge as practicable. Measurements of squares of stakes by taping give useful data on the rate of strain of the ice, and one such square might well be sited at the middle of a transverse line of stakes, and also at other points if time permits. Measurements of velocity and strain rate down longitudinal profiles of valley glaciers or small ice caps are also valuable.

(f) Photographic records. Photographs of glaciers are always valuable to subsequent expeditions in the area, particularly if they are taken from marked points and at known dates and times of day. Photographs should be taken during each survey of an annual programme from all suitable survey points, preferably with a camera of the same focal length.

Where routine observations are made, the results of such work should be published regularly in the same Journal, and details given of what further data are available and where they can be found.

III. MEASUREMENT OF GEOGRAPHICAL DATA NOT REQUIRING ANNUAL REPETITION.

Some of the data needed to give a description of a glacier are not subject to annual variation in the same way as the various data discussed in the previous section.

(a) Position and shape of the glacier bed. The shape of the glacier bed can be found by drilling through the ice at various points, by seismic sounding or by measurements of gravity. All three methods involve costly apparatus and are not to be undertaken lightly. The gravity method is the easiest to do in the field, but its interpretation is most complex, particularly in the case of a valley glacier. For a small ice cap it is more

accurate. Specialist advice should be sought by anyone attempting depth measurements who is not well versed in one of the techniques involved.

(b) Mapping and study of moraines. The terminal moraines below the snout of a glacier give some idea of the shape and extent of the glacier in former times. A map of these should be made, and the vegetation cover should be noted.

(c) Glacier surface forms. The presence or absence of various types of banding on the glacier should be noted, as also the position and direction of the main crevasse patterns. The amount of moraine cover on the ice and its nature and distribution should be noted. These observations will not need repeating annually, but at intervals (of about 10 or 20 years?) it would be of interest to see whether the situation has changed.

IV. MEASUREMENTS OF OTHER QUANTITIES OF INTEREST TO GLACIOLOGICAL THEORY.

Measurements to test, or provide data for, current glaciological theories are naturally much more varied, and it would be foolish to attempt to lay down rules for such work. All that we shall do here is to note some properties of glaciers, other than those mentioned above, which can and should be recorded on a number of glaciers, and which will provide data which glacier theorists are certain to need some time, even if they do not now, and to mention some experiments that seem to be indicated by the current theories.

Anyone starting such work should try to find out what previous work has been done on the subject, both in the field and in theoretical discussion. In this the bibliographies that appear at the back of each issue of the Journal of Glaciology will be found of help The general trends of recent research have been summarized by Seligman, and by Baird and Sharp. The recent developments in the theory of glacier flow have been reviewed by Sharp.

As has already been mentioned above, it is most desirable that the glaciers selected for any such measurements shall, as far as possible, be ones for which measurements of standard glaciological data are available.

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(a) Measurement of glacier flow at depth. This is probably best done using a pipe and inclinometer. Measurements at characteristic points on a glacier are urgently needed, and their value would be enhanced if measurements on two pipes, one ahead of the other, could be made simultaneously, so as to give not only the longitudinal velocity, but also the longitudinal strain rate of the glacier at all depths. Naturally, measurements on 4 pipes in a square array would be better still. Even if only one pipe is used, it is essential for the interpretation of the results that measurement of the surface strain rate, i.e. of the rate of change of the distances between stakes in a square array at the top of the pipe, should be made.

Measurement of flow at depth at a series of points down a long glacier would be most valuable, but measurements even on different glaciers are helpful; the aim must be first to get some idea of the results (i) for a valley glacier (c.f. Gerrard, Perutz and Roch) in the firn region, near the firn line of a

glacier without an ice fall, at the top of an ice fall in the crevassed region, in the middle of an ice fall, at the foot of an ice fall, in the middle of the ablation region, and very near the snout. (ii) for a piedmont glacier in the ice piedmont. (iii) on an ice cap at the centre, and about $\frac{1}{2}$ way and $\frac{7}{8}$ way to the edge. Finally all these measurements should be made on both a temperate and a polar glacier.

(b) The slipping of glaciers over their beds. Whether a glacier is slipping over its bed at depth can only be discovered in an experiment involving a pipe, a tunnel through the ice, or a tunnel through the bedrock. However, whenever a pipe or tunnel is available, an effort should be made to discover the amount of such slipping and whether it is continuous or jerky. Where the glacier surface abuts onto rock without intervening moraine, it is possible to make measurements of slip that are far less difficult, and this should be attempted where possible. It is particularly important that measurements of this kind be made on glaciers that are not temperate, i.e. where the temperature at depth is sub-zero, as it is not yet known whether such glaciers ever slip on their beds, but it is also important in temperate glaciers, as the amount of slipping on the bed is believed to be a considerable part of glacier flow in some cases, and the theory of it is still in an elementary state.

(c) Detailed measurements of surface velocities and strains. Although the measurement of glacier flow velocity has been reckoned a standard glaciological variable, and it was discussed in section II (e), the accurate measurement of surface strains involves somewhat different techniques and has not been adopted in any routine studies as yet. As the relative velocity of stakes on a glacier can be measured by taping and levelling, and as this gives the surface strains directly, the less accurate theodolite work is used in such measurements only to give a general indication of the velocity itself, and as a check on gross errors. The main surveying method will be taping and levelling of an array of stakes. This work would be of great use if it could be extended to cover the entire surface of a small glacier, and can also be employed in regions on larger glaciers where interesting changes are occurring. Such regions are the top of an ice fall, the bottom of an ice fall where wave ogives and Forbes bands form, parts of a glacier where there is a sharp change in general flow direction, such as a sharp bend in the valley or where an ice piedmont opens out from a valley glacier, and at a constriction in a valley where the ice is squeezed transversely. In all these regions it would be of great interest to know the detailed velocity pattern, and of the relation of such a pattern to any bands or crevasses formed. Again measurements on both temperate and non-temperate glaciers are desirable.

(d) Studies of the granular structure of ice. Studies of the size, shape and orientation of the ice crystals at various points in glaciers should be made systematically on all the standard glacier types, both temperate and polar. Care should be taken to note whether there is banding in the ice, and, if there is, the shapes and orientations of the grains should be related to the orientation of the bands. The relation between the shape and orientation and the rate of strain of the glacier or the direction of flow should also be determined. Some thin sections should be photographed in the field and then kept beneath cold paraffin to see whether they recrystallize. This tells us whether there were internal stresses locked up in the grains.

(e) Studies of glacier banding. These should be made at all parts of typical glaciers. The bands should be mapped, that is to say their location in the glacier should be carefully

determined, and the dip and strike of the bands should be found and related to the glacier surface. If the bands contain materials other than air and ice this should be noted, and if possible samples of the material should be analysed. Pollen analysis has already proved of value in tracing the origin of bands, and there are many problems that could probably be solved by employing it, the problem of band formation below ice falls being one of them. A warning must be given, however, that pollen analysis is a specialist job.

If there are stones in the bands the orientation of their long axes relative to the dip of the bands and the direction of glacier flow should be determined. This will help to show whether the band has had active shear along it.

(f) Studies of the thermal balance of glaciers. Measurement of the incoming and outgoing radiation, both short and long wave, of the structure of the wind above the glacier (i.e. of the mean velocity, temperature and humidity as a function of height) and measurement of the heat flowing up through the ice should be made and compared with ablation. Hoinkes and Untersteiner have made such measurements in Austria, but further work is needed at different altitudes and in different climatic regions. The measurements are of much greater value if continued from year to year.

(g) Studies of air in glacier ice. The content of air in glacier ice, both in the form of bubbles and dissolved, should be determined for points in a glacier that represent successive positions occupied by a particular volume of snow. These experiments will be very hard to do, principally because of the enormous variation in bubbliness shown by glacier ice, but should be very worthwhile, as little is known about the history of the air trapped in the firnification process and how, if it does, it escapes from the glacier. Again measurements on non-temperate glaciers may be very different from those on temperate ones, where percolating melt water may play an important role.

(h) Studies of the flow of glacier streams. The location of glacier streams on, within and under the ice should be studied. The method by which moulins are formed, and their depth, should be determined in particular with relation to crevasse patterns and other ice structures. The typical locations of melt water streams on and within a glacier should be studied in three dimensions. The depth to which melt water streams descend in cold ice should be investigated, and their influence on the general thermal regime of such glaciers determined.

(i) Studies of dead ice and moraines. The movement and melting of 'dead ice' under moraine at the side and end of glaciers should be measured over a long period, and borings should be made in moraine to estimate the amount of ice remaining below. The results should be used to determine the time needed before a moraine loses all the ice beneath it. Observations should also be made of any sorting of the overlying debris which may occur.

(j) Studies on glacial erosion. Direct measurements of glacial erosion are much needed. The widest use should be made of any places where either frost action or glacial smoothing or both affect a rock face and to which access can be obtained over a period of years. Bergschrunds, side wall gaps, rock tunnels reaching to the bed of a glacier and tunnels through the ice itself should be used. The order of magnitude of the effects is not known, and so it is hard to advise on the method to be employed, but perhaps if a tunnel reaches to the bed of a glacier where a smooth rock face is available, a hole could be drilled and its depth measured accurately, it could then be filled with some substance that, though insoluble in water, can be dissolved

out by some other liquid that does not affect the rock. The glacier could then be left to do its work for a few years, after which the site should be re-excavated, the patch found again, the substance removed and the depth again measured. Other ideas may occur to the reader.

In any such test careful studies of the rock type, its structure, and the orientation and spacing of joints should be made.

The method of removal of large blocks should also be studied in more detail, and further measurements taken of the frequency of freezing and thawing in cracks should be made.

(k) Studies on glacial deposition. Tunnels dug under the snouts of glaciers should be used to investigate the nature, structure, and if possible rate of deposition of till. If it is possible to locate a drumlin field under ice, then pipe measurements should be used to determine the flow pattern of ice in the vicinity. The structure and location of any moraines or eskers emerging from the ice should be studied, both where the formation is on dry land and where it is beneath a lake. The mechanism of deposition of moraine is still not fully understood, particularly beneath water. Measurements of the orientation of stones in deposits immediately under the ice should be correlated with the orientation of stones actually incorporated in the ice (a) in visible bands and (b) in bulk ice with no visible bands. Measurements should be made of the extent to which till lying below the ice is being dragged by the ice. An ideal case for this study would be where ice was advancing over till laid down by ice flowing in a different direction, as then measurements of velocity could be supplemented by orientation measurements.

V. MEASUREMENTS SUGGESTED DIRECTLY BY CURRENT THEORIES.

Among the problems posed by current glaciological theories are the following:

(a) The relation between wave ogives, Forbes bands and compressive flow. Detailed measurements of surface flow where the waves form and decay, combined with depth measurements, ablation measurements and measurement of velocity at depth are needed to establish the causes and interrelation of these phenomena at the bottom of an ice fall. Similar measurements at a constriction where longitudinal bands form would be of equal interest.

(b) Anomalous glacier advances. The idea that some advances are due to polar glaciers becoming temperate should be checked by temperature and surface profile measurements. In the thickness is decreasing and the temperature rising then the advance can be attributed to a change of glacier type. Similarly if any anomalous glacier retreats occur in a region where the climate is believed to be getting colder and/or more snowy, then measurements of level of the surface should show whether the glacier is cooling down, and hence getting thicker and shorter, or whether it is retreating normally, with its surface sinking.

(c) Direction of flow and surface slope. Current theories indicate that the velocity of glacier flow should in plan be parallel to the surface gradient, i.e. perpendicular to the contours. This should be checked on glaciers where the surface slope remains constant over lengths of the order of the depth, perhaps small ice caps might be most suitable. For cases where the surface slope is not constant over such areas tests as to which slope is parallel to the direction of flow should be made. (It is suspected that the surface slope over distances of the order of the depth is the important one, but this is now known.)

This should be tested for temperate and polar glaciers.

(d) Theory of temperature distribution in a glacier. Robin's theory of the distribution of temperature in ice sheets has implications for the distribution in smaller ice masses such as polar valley glaciers and ice caps. This theory should be checked by measurements in two similar glaciers in regions with differing amounts of accumulation.

(e) Theory of formation of penitentes. The micro-meteorological theory of the formation of penitentes suggested by Lliboutry should be checked by careful measurements if possible.

VI. PUBLICATION OF RESULTS OF EXPEDITIONS.

All expeditions which make measurements of glaciers, whether of the kind described as routine or those described in the last two sections, should prepare a report on their work, including measurements, and a representative collection of photographs, and this should be duplicated and one copy sent to the British Glaciological Society, and another to an equivalent organization in the country in which the work was done. If the work was in polar regions, then a copy should also be sent to the Scott Polar Research Institute. If further copies are available, the British Glaciological Society will be pleased to publicise their availability.

Clearly if original work of value and general interest has been done, scientific papers for submission to learned journals will be prepared as well, but this should not supercede the writing of a full report, which may well include other topics not of importance in the consideration of the main object of the expedition but of great importance to anyone subsequently visiting the glacier for other purposes. If more numerical data is obtained than can conveniently be included in a duplicated report, then the person who retains such data should be specified in the report.

VII. GENERAL REMARKS AND CONCLUSION.

Where non-routine measurements are planned, the expedition ought if possible to be planned so that such measurements are first priority. If the measurements can be taken on a relatively accessible glacier, it will almost always be best to take them there. Some of the measurements suggested necessarily involve going to relatively inaccessible places, and in such cases the expedition will frequently have to be in collaboration with other persons going for different reasons. In such a case every effort should be made to secure the maximum of cooperation in planning so that the glaciological programme is not unduly hindered. Work on other glaciological observations, such as routine ones, must always take second place to the measurements which is the prime aim of the expedition to get.

In order to assist in the correlation of data, it would be desirable to get some measure of international agreement, official or unofficial, on the glaciers to be studied, the form and method of making routine observations, and the publication of their results. Glaciologists might note the degree of such cooperation achieved by the synoptic meteorologists.

VIII. REFERENCES TO TYPICAL PAPERS.

The references below show the kind of work which can be undertaken under the various headings in sections III, IV and V. The bibliography is not exhaustive, and papers in English have been preferred. The work of the authors is not necessarily endorsed by the Sub-Committee.

Section III(a). RACT-MADOUX, M., and REYNAUD, M. L'exploration des glaciers en profondeur; travaux de la Mer de Glace. La Houille Blanche, 6e Ann., No. Special A, 1951, p. 299-308 (Borings and seismic work).
LITTLEWOOD, C.A. Gravity measurements on the Barnes Icecap, Baffin Island. Arctic, Vol. 5, No. 2, 1952, p. 118-24.

Section IV(a). GERRARD, J.A.F., PERUTZ, M.F., and ROCH, A. Measurement of the velocity distribution along a vertical line through a glacier. Proceedings of the Royal Society, Ser. A, Vol. 213, No. 1115, 1952, p. 546-58.

Section IV(b). McCALL, J.G. The internal structure of a cirque glacier. Report on studies of the englacial movements and temperatures. Journal of Glaciology, Vol. 2, No. 12, 1952, p. 122-31.

Section IV(d). SELIGMAN, G. The growth of the glacier crystal. Journal of Glaciology, Vol. 1, No. 5, 1949, p. 254-67.

Section IV(e). UNTERSTEINER, N. Some observations on the banding of glacier ice. Journal of Glaciology. Vol. 2, No. 17, 1955, p. 502-06.
GODWIN, H. Pollen analysis of glaciers in special relation to the formation of various types of glacier bands. Journal of Glaciology, Vol. 1, No. 6, 1949, p. 325-32.

Section IV(f). HOINKES, H. Measurements of ablation and heat balance on Alpine glaciers. Journal of Glaciology, Vol. 2, No. 17, 1955, p. 497-501.

Section IV(g). BADER, H. The significance of air bubbles in glacier ice. Journal of Glaciology, Vol. 1, No. 8, 1950, p. 443-51.

Section IV(j). BATTLE, W.R.B., and LEWIS, W.V. Temperature observations in bergschrunds and their relationship to cirque erosion. Journal of Geology, Vol. 59, No. 6, 1951, p. 537-45.

Section V(a). GLEN, J.W. Measurement of the deformation of ice in a tunnel at the foot of an ice fall. Journal of Glaciology, Vol. 2, No. 20, 1956, p. 735-45. and subsequent papers of this series.

Section V(d) for theory see ROBIN, G. de Q. Ice movement and temperature distribution in glaciers and ice sheets. Journal of Glaciology, Vol. 2, No. 18, 1955, p. 523-32.

Section V(e) for theory see LLIBOUTRY, L. The origin of penitents. Journal of Glaciology, Vol. 2, No. 15, 1954, p. 331-38.

General references were given in section IV at the end of the introductory paragraph.

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